

NUCLEAR ENERGY AND WASTE DISPOSAL IN THE AGE OF FUEL RECYCLING

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ABSTRACT

The magnitude of humanity's energy needs requires that we embrace a multitude of various energy sources and applications. For a variety of reasons, nuclear energy must be a major portion of the distribution, at least one-third. The often-cited strategic hurdle to this approach is nuclear waste disposal. Present strategies concerning disposal of nuclear waste need to be changed if the world is to achieve both a sustainable energy distribution by 2040 and solve the largest environmental issue of the 21st century – global warming. It is hoped that ambitious proposals to replace fossil fuel power generation by alternatives will drop the percentage of fossil fuel use substantially, but the absolute amount of fossil fuel produced electricity will be kept at or below its present 10 trillion kW-hrs/year. Unfortunately, the rapid growth in consumption to over 30 trillion kW-hrs/year by 2040, means that 20 trillion kW-hrs/yr of non-fossil fuel generated power has to come from other sources. If half of that comes from alternative non-nuclear, non-hydroelectric sources (an increase of 3000%), then nuclear still needs to increase by a factor of four worldwide to compensate. Many of the reasons nuclear energy did not expand after 1970 in North America (proliferation, capital costs, operational risks, waste disposal, and public fear) are no longer the intractable problems once thought. The WIPP site in New Mexico, an example of a solution to the nuclear waste disposal issue, and also to public fear, is an operating deep geologic nuclear waste repository in the massive bedded salt of the Salado Formation. WIPP has been operating for eight years, and as of this writing, has disposed of over 55,000 m³ of transuranic waste (>100 nCi/g but <23 Curie/liter) including some high activity waste. The Salado Formation is an ideal host for any type of nuclear waste, especially waste from recycled spent fuel. From the standpoint of addressing operational and environmental risk, as well as public fear, WIPP has had extensive human health and environmental monitoring. The Carlsbad Environmental Monitoring and Research Center at New Mexico State University, located in Carlsbad, NM, has been the independent monitoring facility for the area around WIPP from 1993 to the present, i.e., from six years before disposal operations began to nine years of waste disposal operations (www.cemcr.org). Based on the radiological analyses of monitoring samples completed to date for area residents and site workers, and for selected aerosols, soils, sediments, drinking water and surface waters, there is no evidence of increases in radiological contaminants in the region of WIPP that could be attributed to releases from WIPP.

THE ROLE OF NUCLEAR IN ACHIEVING A SUSTAINABLE ENERGY DISTRIBUTION BY 2040.

As we approach global peak oil availability in the next decade, we must be able to diversify into the many other energy sources available in order to achieve a sustainable energy production that will allow the American economy to grow without intermittent shortages, security vulnerabilities, extreme costs or environmental degradation (Wright and Conca, 2007). Energy distribution depends strongly upon the locality (Table 1) with the United States having more coal and nuclear than the world at large. Using best-estimate population growth and global energy consumption projections (United Nations 2004), world population will exceed 9 billion by 2050 and energy consumption will top 40 trillion kW-hrs/year (Figure 1, and Deutch & Moniz 2006). With determined conservation and efficiency programs, cultural changes and new construction strategies, this might be reduced to 30 trillion kW-hrs/year, although present trends indicate this to be unlikely (Energy Information Administration, 2007, Stix 2006). Ambitious proposals to replace conventional fossil fuel (coal, oil and gas) power generation by alternative energy sources hope to drop the percentage of fossil fuel use by half from its present two-thirds to one-third (Figure 2). Unfortunately, because of the rapid growth in consumption, a third of 30 trillion kW-hrs/year is 9.8 trillion kW-hrs/year, which is the same absolute amount of fossil fuel used today (Figure 1). This means that CO₂ emissions will not drop appreciably, and CO₂ capture, sequestration, or other technologies will have to solve the emission problem.

Therefore, if we are successful in cutting fossil fuel use to a third, the remaining 20 trillion kW-hrs/yr of generated power must come from other sources than non-fossil fuel (Figure 1). If half of this, or 10 trillion kW-hrs/yr, comes from alternative non-nuclear sources (an increase of 3000% and beyond any anticipated goal), then

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World Power Consumption (trillion kiloWatt-hours per year)

TABLE 1. Energy Distribution by Country or Region.

<i>World</i>	<i>Canada</i>
8% oil	33% oil
39% coal	9% coal
20% gas	25% gas
17% nuclear	7% nuclear
15% hydroelectric	25% hydroelectric
<i>European Union</i>	<i>United States</i>
30% coal	50% coal
18% gas	19% gas
32% nuclear	19% nuclear
11% hydroelectric	6% hydroelectric
6% oil	6% other
3% other	
	<i>California</i>
<i>New Mexico</i>	2% coal
77% coal	49% gas
18% gas	15% nuclear
4% wind	22% hydroelectric
1% other	11% other

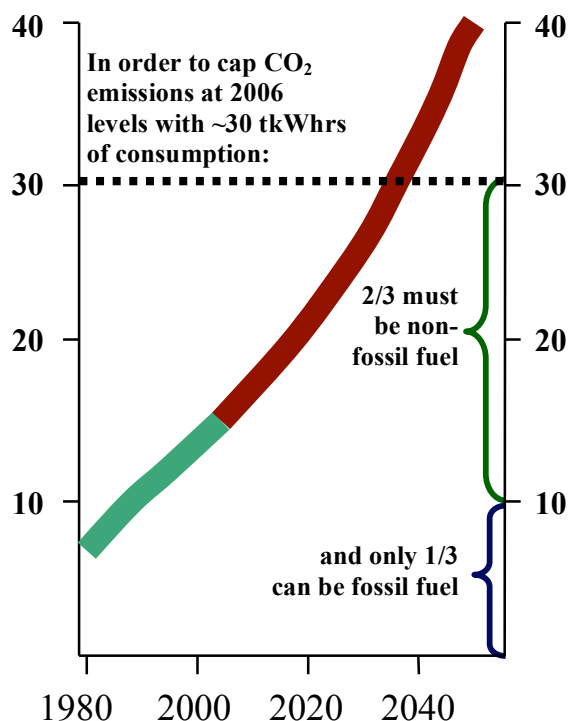
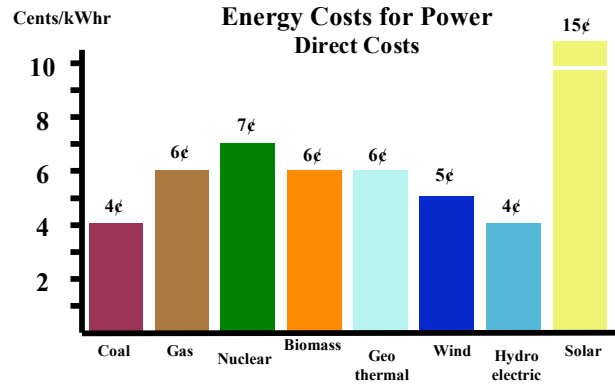
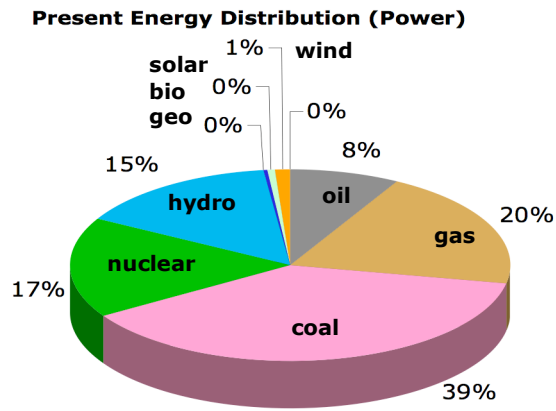


Fig. 1. World energy consumption from 1980 projected to 2050. It is imperative that the total energy consumed does not exceed about 30 trillion kW-hrs/year in order to be able to cap CO₂ emissions at present levels. After Deutch & Moniz (2006).

nuclear still needs to increase by a factor of four to compensate. If not, fossil fuel use will double and CO₂ concentrations in the atmosphere will exceed 600 ppm. France is an example of how this strategy can be successful. Between 1980 and 1987, when France implemented its changeover to nuclear energy, generating 80% of its power from nuclear, its CO₂ emissions dropped from 134 million tons/year to 96 million tons/year, at the same time electricity consumption increased 46%. This is the only instance in the world where a major energy-producing country has met the goals of the Kyoto protocol, indeed many times over as this rolled France's emissions back to 1960s levels. Therefore, in order to address global warming and long-term energy sustainability, nuclear energy production must increase significantly, and all countries including the United States need to begin ambitious and sustained construction of new design nuclear power plants to reduce the number of new fossil fuel power plants anticipated over the next generation. Fully 1500 nuclear plants are needed by 2040, more if electric vehicles become the strategy for replacing petroleum-based vehicles, requiring an additional 7 trillion kW-hrs/yr.

ADDRESSING NUCLEAR ISSUES

Nuclear energy slowed substantially in the 1970's for several reasons, one of which was that the United States abdicated its leadership role. The main concern was fear of proliferation, an issue that has become less U.S.-centric with the increase in enrichment capabilities worldwide, with new fuel and reactor designs, and with the possible eventual adoption by the world community of some type of nuclear energy partnership in which nuclear fuel is provided to non-nuclear-capable countries by nuclear countries thereby removing the necessity of non-nuclear countries from developing enrichment capabilities of their own that can be used to produce weapons-grade material.



A Target Sustainable Energy Distribution by 2040 (Power)

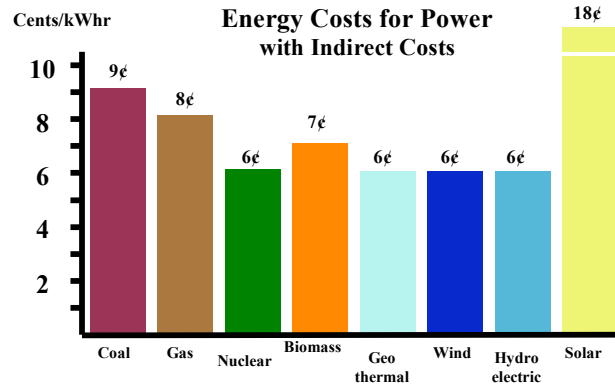
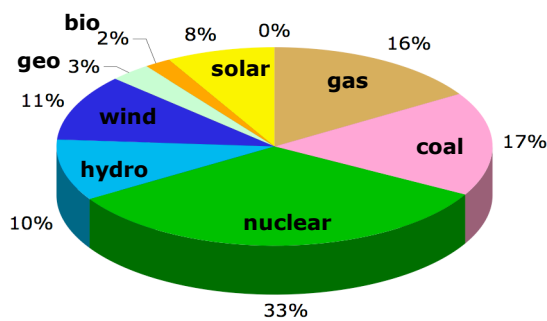


Fig. 2. Present world energy distribution for power (above; 2/3 fossil fuels, 1/6 nuclear, 1/6 hydropower) and a 2040 target distribution (1/3 fossil fuel, 1/3 renewables and 1/3 nuclear).

Fig. 3. Energy Costs/kWhr in the U.S. determined as direct costs (above) and indirect costs (below) which factors in environmental and footprint costs.

Since the fuel costs are much lower than the O&M costs of nuclear power (23% fuel vs. 77% O&M), unlike coal (78% fuel vs. 22% O&M) or gas (91% fuel vs. 9% O&M), this makes economic sense (OECD 2005, NEI 2006). The user country does not need to enrich or dispose, and proliferation is greatly controlled if not removed. The key to success is the ability to recycle spent fuel in the nuclear countries to a sufficient degree to replace fuel as needed and to reduce disposal volumes. If proliferation is no longer the main problem, then the four remaining problems cited against nuclear energy are capital costs, operational risks, public fear, and waste.

Capital costs can be addressed by standardizing reactor designs. Having four or five generic power plant designs would reduce costs and streamline the regulatory process, as occurred in France during the 1990s. Also, new life-cycle costs for all energy sources must factor in indirect costs such as carbon tax, environmental costs and footprint costs as are captured by the European Union's ExternE monetization methodologies (Bickel & Friedrich 2005), and disposal costs. Life-cycle energy costs are shown in Figure 3, with coal the least expensive at 4 cents/kW-hr, and nuclear at 7 cents/kW-hr (Bickel & Friedrich 2005, Deutch & Moniz 2006, Jochem 2006, Kammen 2006, see also websites listed for: Atomic Energy of Canada Limited, U.S. Department of Energy, Energy Information Administration, Association for the Study of Peak Oil and Gas, National Renewable Energy Laboratory, National Energy Institute, American Association of Petroleum Geologists, International Atomic Energy Agency, U.S. Geological Survey, Canadian Center for Energy).

When monetization methodologies are factored into these costs, particularly footprint and carbon taxes, life-cycle energy costs become 9 cents/kW-hr for coal, 8 cents/kW-hr for gas, and only 6 cents/kW-hr for nuclear, becoming as inexpensive as wind. Once built, nuclear energy is the least costly, most efficient energy source there is, with costs just above a penny/kWhr. Nuclear energy has a capacity factor (CF) of 92%, the highest of any energy source (CF ~ 30% for wind, CF ~ 55% for coal) which means the plant is operating almost all the time at nearly full capacity and with constant and dependable output. Finally, nuclear is the only energy source not subsidized by

federal and state governments, but is burdened with nuclear taxes and extremely high finance rates resulting from unwarranted public unease.

The issues of operational risks and public unease can only be addressed by public education, continued monitoring of the existing sites and reactors, and adoption of standardized designs. Even including Chernobyl, the textbook case of a poor design coupled with an incredible degree of human error, the nuclear industry has the safest record of any industry. Standardization would remove any future Chernobyl-type events. In contrast, Americans unwittingly accept over 200,000 deaths each year from iatrogenic means (properly performed medical procedures and prescription drug use), 160,000 from tobacco, 110,000 from alcohol, 60,000 from automobile accidents and 20,000 from the use of coal, yet live in constant fear from the zero deaths per year in the nuclear industry. Even for non-lethal injuries like falling off a ladder or cutting a finger with an exacto-knife, the nuclear industry is the safest. More injuries occur in an office trading stocks than in a nuclear power plant. This extreme inequity and ignorance must be driven home more forcefully.

The remaining issues of nuclear waste disposal and uranium mining can be addressed by recycling spent fuel, and rethinking disposal of that waste stream in a permanent, non-retrievable deep geologic repository.

NUCLEAR WASTE

The critical aspect about nuclear waste unknown to the public and public officials is that there is not much of it. All the spent fuel generated in the United States in the last 60 years can fit on a single soccer field (assuming a PWR assembly dimension of 21.5 cm x 21.5 cm, approximately 100,000 used assemblies, and a regulation soccer field of 100 x 60 yards). Compared to that, the over 100 million tons of solid waste and 2 billion tons of CO₂ generated from coal-fired power plants each year is staggering. Even worse is the greater than 500 million tons of solid chemical and sanitary waste generated each year, and the 2 quadrillion gallons of water requiring waste treatment each year. These are large waste volumes. All the nuclear waste generated in the United States in a thousand years can fit into one repository. It is interesting to note that, while not high enough to be a health concern, living near a coal-fired power plant provides a greater radiation dose than living near a nuclear power plant. This is because coal-fired power plants generate about 3,000 tons of U, Th and their daughter products each year, a small amount compared to the 800 million tons of coal fuel, but still more than the 600 tons of spent fuel generated each year from nuclear. Recycling would reduce this amount of nuclear waste even more.

Contrary to public opinion, nuclear waste is easy to handle, because there is so little of it and radiation is so easy to measure. Unlike chemicals and biologicals, we have been measuring radiation for 80 years, and it has been difficult to get a serious dose. This is why, since commercial nuclear power began in the United States, no one has died or been seriously injured by nuclear waste or by working at a nuclear power plant, the best safety record of any industry or any job.

CHARACTERISTICS OF A GEOLOGIC REPOSITORY FOR RECYCLED NUCLEAR WASTE

Looking beyond the current Yucca Mountain repository program, characteristics of a suitable geological repository for the disposal of nuclear waste from an expanded fleet of U.S. nuclear reactors might include the following favorable characteristics (McEwen 1995, EPRI 2006)

- i. a simple hydrogeology,
- ii. a simple geologic history,
- iii. a tectonically interpretable area,
- iv. isolation robustly assured for all types of wastes (no vitrification or reforming necessary),
- v. minimal reliance on engineered barriers to avoid long time extrapolation of models for certain types of performance,
- vi. performance that is independent of the canister, i.e., canister and container requirements are only for transportation, handling and the first several hundred years of peak temperature after emplacement in a repository, and
- vii. a geographic region that has an existing and sufficient sociopolitical and economic infrastructure that can carry out operations without proximity to a potentially rapidly growing metropolis (unlikely to ever have human habitation anywhere near the site).

These characteristics are similar to an optimal repository for spent nuclear fuel except that there is no requirement of retrievability, since the recycle waste has already been reprocessed to remove useful components. Especially

important is the removal of the need to vitrify higher-activity waste prior to disposal in a repository that meets these criteria.

Two rock types that fit these characteristics are argillaceous rocks (claystones and shales) and bedded salts. Many studies have focused on argillaceous sites, particularly in Canada and Europe with some strong technical arguments (Nuclear Energy Agency 2001); similarly for salt deposits (McEwen 1995, National Academy of Sciences 1970). Although salt deposits exist throughout the world (Zharkov 1984), many are not sufficiently massive, have too many clastic interbeds, are tectonically affected, or are near population centers. Salt domes and interbedded salts are less optimal than massive bedded formations from a hydrologic standpoint, particularly within the United States where diapiric movement can exceed 1 mm/yr (McEwen 1995) and spline fractures can act as hydraulic conduits. Still, there are many viable salt deposits globally that meet these criteria (Zharkov 1984, Waughugh & Urquhart 1983, Karalby 1983).

MASSIVE BEDDED SALT OF THE SALADO FORMATION

The Salado Formation in the Permian Basin of southeast New Mexico is one such formation that satisfies all of the above characteristics. The Salado Formation is a massive bedded salt deposit that has a simple hydrogeology with no dual-porosity or multi-component properties. The Salado has had a simple geologic history and is in a tectonically quiet area. The Salado is a simple geologic unit exhibiting self-healing rock mechanical properties, such that the host rock cannot maintain open and connected fractures or pores, resulting in an overall hydraulic conductivities $\leq 10^{-14}$ m/s (Beauheim & Roberts 2002) and diffusion coefficients $\leq 10^{-15}$ m²/s (Beauheim & Roberts 2002, Conca *et al.* 1993). The unit provides performance that is independent of waste type, engineered barriers, and water content. The unit provides an environment that does not require long-term, or even short-term, survival of the canister. Container requirements are only for transportation and handling pre-placement. Geographically, there are many sites underlain by the Salado Formation that are remote from human habitation yet have sufficient socioeconomic infrastructure to support disposal operations.

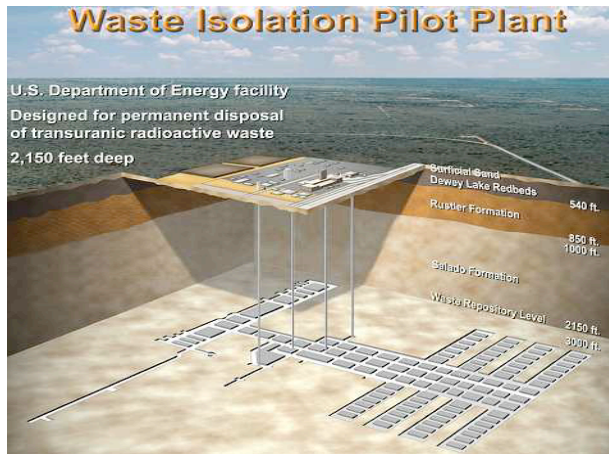


Fig. 4. The Waste Isolation Pilot Plant (WIPP), the only operating deep geologic nuclear waste repository, is excavated 700 meters below the surface in the massive salt of the Salado Formation, and has operating successfully since 1999.



Fig. 5. Over 10,000 nuclear waste drums and standard waste boxes filling 1 of 56 rooms to be filled at WIPP over a 20-year period. Almost 25 rooms have been filled as of June 2008. Note the higher activity remote handled waste plunged into boreholes in the wall to the right and plugged.

If these properties and conditions sound familiar, it is because the Salado Formation is already host to an operating deep geologic nuclear waste repository, called the Waste Isolation Pilot Plant, or WIPP, shown in Figure 4. WIPP, near Carlsbad, NM has been operating for over nine years and, as of this writing, has disposed of over 55,000 m³ of waste in over 100,000 containers, equivalent to about 280,000 fifty-five gallon drums (Figure 5, see also <http://www.wipp.energy.gov>).

But recently, WIPP has begun accepting waste containing radionuclides that emit more penetrating gamma radiation, referred to as Remote Handled (RH) waste. RH waste has surface exposures greater than 200 mrem/hr, so must be shielded and remotely handled. It still must have transuranic activity concentrations greater than 100

nanocuries per gram of waste, but the upper limit is 23 Curie/liter. These higher activities mostly result from gamma emissions from the decay of isotopes such as ^{137}Cs and $^{90}\text{Sr}/^{90}\text{Y}$. This upper limit is similar to processed high-level waste such as high level waste sludge or its treated form as vitrified glass. The RH waste is shielded, shipped in a 72B casket (Figure 6), and inserted remotely into a horizontal borehole in the disposal room wall (at right in Figure 5). These boreholes are single-drum-width in diameter and three drum-lengths deep with a shield plug, and are emplaced on 8-ft centers along the wall, similar geometrically to many international high-level waste disposal strategies. Another unique feature of the Salado is the ease, safety and low-cost of mining operations versus hard rock.

An important issue relating to disposal of reprocessed waste, or any high-thermal waste, in the Salado Formation is the presence of fluid inclusions in the salt. The water content in the salt is extremely low (between 0.5 and 1.5% by volume) and exists primarily as fluid inclusions of brine and brine along grain boundaries. Fluid inclusions have been studied extensively with respect to high activity waste disposal because inclusions can migrate under a significant thermal gradient, e.g., $1.5^\circ\text{C}/\text{cm}$, by dissolution of salt on the up-gradient side and re-precipitation on the down-gradient side (Roedder 1984). This process encourages brine to migrate towards the waste. In most international high-level waste programs, this has been viewed as a problem because the canisters and any engineered barriers are required to survive intact anywhere from 10,000 to 100,000 years and interactions with brine, however small the volumes, could be detrimental to canister performance. However, in the Salado Formation, the canister does not need to survive after emplacement, there is no need for engineered barriers, and a halo of increased water content within or around the disturbed rock zone is of no consequence from a repository performance standpoint.

In addition, after fluid inclusions have migrated and the salt has recrystallized behind them, the hydraulic conductivity is still $< 10^{-12}$ m/s and the diffusion coefficient is even lower because of the lowered water content (Conca *et al.* 1993). In fact, at WIPP, the performance assessment assumes a repository with various amounts of water inundation probabilistically distributed, from dry to completely flooded, with completely breached and corroded containers. Therefore, fluid inclusion migration is not an issue for nuclear waste disposal in the Salado Formation or any other salt deposit with similar characteristics (McEwen 1995; Beauheim and Roberts 2002).

VII. ENVIRONMENTAL MONITORING

From the standpoint of addressing operational and environmental risk, as well as public fear, WIPP has had extensive human health and environmental monitoring from six years before operations began to over nine years of waste disposal operations (Carlsbad Environmental Monitoring and Research Center 2007). The Carlsbad Environmental Monitoring and Research Center is in the Institute for Energy and the Environment, in the College of Engineering at New Mexico State University. Located in Carlsbad, NM, CEMRC has been the independent monitoring facility for the area around WIPP from 1993 to the present (www.cemcr.org). Based on the radiological analyses of monitoring samples completed to date for area residents and site workers, and for selected aerosols, soils, sediments, drinking water and surface waters, there is no evidence of increases in radiological contaminants in the region of WIPP that could be attributed to releases from WIPP. Levels of radiological and non-radiological analytes measured since operations began in 1999 have been within the range of baseline levels measured previously, and are within the ranges measured by other entities at the State and local levels since well before disposal phase operations began in 1999. Constituents and properties measured by the monitoring program in these media include, but are not limited to, gross alpha/beta, ^7Be , ^{212}Bi , ^{213}Bi , ^{214}Bi , ^{144}Ce , ^{249}Cf , ^{60}Co , ^{134}Cs , ^{137}Cs , ^{152}Eu , ^{154}Eu , ^{40}K , ^{233}Pa , $^{234\text{m}}\text{Pa}$, ^{212}Pb , ^{214}Pb , ^{106}Rh , ^{125}Sb , ^{208}Tl , ^{228}Ac , ^{234}U , ^{235}U , ^{238}U , ^{230}Th , ^{232}Th , ^{228}Th , ^{241}Am , ^{238}Pu , $^{239,240}\text{Pu}$, various VOCs, and many inorganic constituents normally analyzed in waters, particularly RCRA constituents. The *in vivo* bioassay (whole body counting) program at CEMRC participates in the Department of Energy's *In Vivo* Laboratory Accreditation Program (DOELAP) via WIPP, and is currently accredited to perform the following direct bioassays - transuranium elements via L x-ray in lungs, ^{241}Am , ^{234}Th , ^{235}U , fission and activation products in lungs including ^{54}Mn , ^{58}Co , ^{60}Co and ^{144}Ce , and fission and activation products in total body including ^{134}Cs and ^{137}Cs (and ^{57}Co , ^{88}Y and ^{133}Ba).

As an example of monitoring results, the gross alpha and beta activities for airborne particulate matter (aerosols) collected from WIPP exhaust air is shown in Figure 7 for the last eight years, expressed as *activity concentrations*, calculated as the activity per unit volume of air sampled (mBq m^{-3}). Data points are distinguished by color, with red being pre-disposal, blue being operational, and black being Station A backup results. The minimum detectable activity concentrations for gross alpha were ≈ 0.1 mBq m^{-3} , while for gross beta is ≈ 0.2 mBq m^{-3} . Aerosols have been the major focus of the monitoring effort because, in the event that radioactive or chemical contaminants are

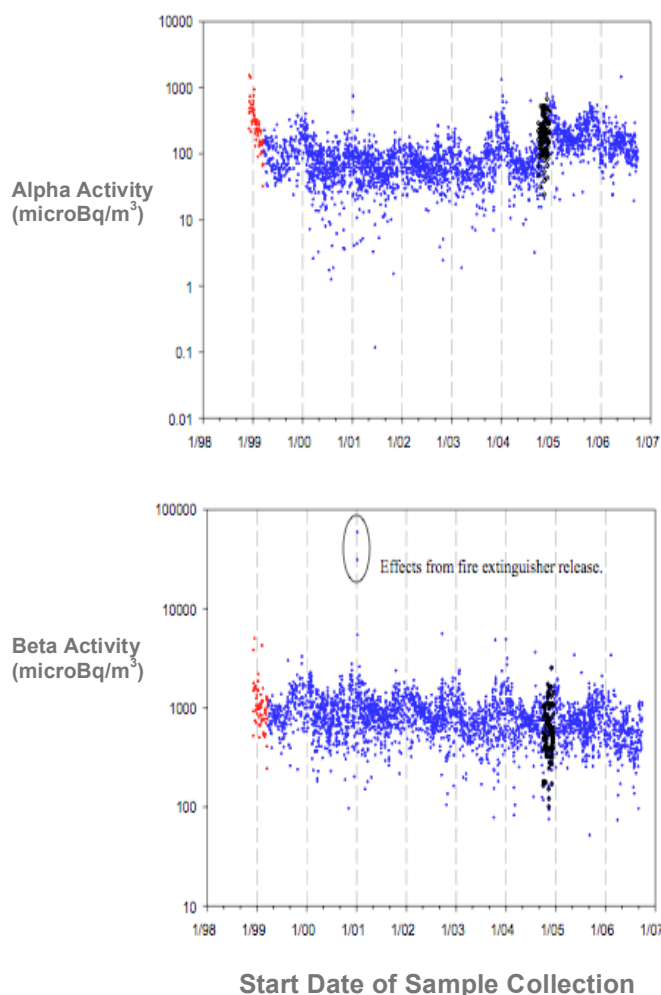


Fig. 6. Remote Handled nuclear waste (>100 nanoCi/gram of waste but <23 Ci/liter), some of it from reprocessing, being transported to the WIPP site in New Mexico in a 72B cask.

Fig. 7. Timeseries plots of gross alpha and gross beta activity concentrations of aerosols on filters sampling air exiting the WIPP underground (Station A FAS). Red points denote pre-disposal samples, blue points are for operational samples and black points are for samples collected with the back-up sampler.

released from WIPP, these materials could be rapidly dispersed through the atmosphere and spread throughout the environment. CEMRC monitors two types of aerosols in the area of WIPP. Station A, an above-ground fixed air sampling platform, provides a way to monitor for releases of radionuclides and other substances in the exhaust air from the WIPP (Figure 7). Station A is located where radioactive or hazardous materials would most likely first be detected in the event of a release. CEMRC commenced sampling of the WIPP exhaust air at Station A on December 12 1998. The samples are collected on 47 mm diameter membrane filters with the use of a shrouded probe, commonly referred to as a fixed air sampler or FAS. The airflow through the FAS is approximately 170 liters per minute. The FAS sample filters are normally changed daily. All the analyses of the FAS filters are performed according to methods detailed in CEMRC document-controlled, standard operating procedures. After the samples are returned to the laboratory, the individual filters are first weighed to determine mass loadings, and after allowing for the decay of short-lived radon daughters, they are counted for gross alpha/beta activities for 1200 minutes using a low-background gas proportional counter (a Canberra LB4100 and, starting in 2006, a Protean MPC9604).

The essence of the strategic design for the monitoring program, including the studies at Station A, has been to compare pre- vs. post-disposal data. The first radioactive waste shipments were received at the WIPP on March 26, 1999, and this is considered the cut-off date separating the pre-disposal phase from the post-disposal or operational phase. The WIPP first received mixed waste on September 9, 2000, and therefore data for samples collected prior to that date compose a pre-mixed waste baseline for the elemental data while those collected afterwards are considered operational. The gross alpha and beta activities (Figure 7) in the samples collected prior to the receipt of the first waste shipment represent the pre-disposal background, and the bulk of the activity in those samples was due to naturally occurring radioactive materials, specifically radon daughters. As shown in Figure 7, the pre-operational

gross alpha activity concentrations were high compared with the annual mean values for the next five years. Gross alpha and beta activities exhibit clear seasonal variability with peaks occurring in winter. An especially pronounced annual cycle in alpha activity concentrations, with high values in December and January and low values mid-year is seen in 2004 to 2005. After 2005, alpha activities appear to have gone back up to pre-operational levels, while beta remains slightly lower than pre-operational levels.

After gross alpha and beta measurements, elemental and gamma-ray analyses are conducted on weekly composites of the FAS filters. Individual FAS filters are digested using a mixture of strong acids in a microwave digestion unit, and weekly composites were prepared from the digestates of the individual filters. The weekly composites are then analyzed for a suite of trace elements with the use of a Perkin-Elmer Elan inductively coupled plasma-mass spectrometry (ICP-MS). The ICP-MS methods can provide data for up to ~35 elements, but in practice the concentrations of some elements, including As, Be, Cd, Er, Eu, Sc, Se, Sm, Tl and V are often below detectable or quantifiable levels, and a second set of elements (notably Ag, Li and Sn) has variable concentrations in blank filters which makes their quantification difficult. Analyses of gamma emitters are performed on the same weekly composites as used for the elemental studies; gamma analyses are done using a low-background, high-purity Ge well detector and a count time of 24 hours.

Finally, quarterly, or more recently, monthly composites are prepared from the weekly composites, and these are used for the determination of actinide activities. Only one half of the composite sample is normally used for the determination of the actinide activities. The remaining aliquot is archived. The composite sample is evaporated to dryness, and the residue is digested in perchloric acid to destroy the black residue, which consists mostly of diesel exhaust particulates. This process ensures that fluorine is completely removed and all traces of organic filter residue have been oxidized. The actinides are then separated as a group by co-precipitation on $\text{Fe}(\text{OH})_3$. After dissolution, Pu, U, and Am are separated by anion exchange and extraction chromatography, and the sample planchettes are finally prepared for alpha spectrometry using rare-earth micro-coprecipitation.

Figure 7 also shows the sensitivity of the monitoring program that was demonstrated in January 2001 when CEMRC found two samples with elevated gross beta activity concentrations in the Station A sample filters. Follow-up investigations eventually traced the source of the beta emitters to the discharge of a fire extinguisher underground, but the incident was more notable because it demonstrated for the first time the ability of the monitoring system to detect a non-routine event. A second, more significant incident occurred when scientists from CEMRC reported that they had detected a small quantity of Pu in a composite aerosol sample from the second calendar quarter of 2003. This discovery was later corroborated by other site monitoring programs through the analyses of samples that were independently collected and analyzed. The activity was extremely low and well-within historic ambient air background, but indicated the ability of the monitoring program to detect radionuclides of interest at any level above the MDC.

In addition to environmental monitoring, WIPP has addressed public concerns by developing a network of acceptable nuclear waste transportation routes throughout the United States, including many diversion routes around population centers. WIPP's perfect safety record has gone a long way towards increased public acceptance and confidence. Finally, the issue of remoteness from population centers is handled very well by the Salado Formation near WIPP, where the nearest towns are over 30 miles away (Carlsbad, Hobbs, Eunice, Otis and Loving, NM) and the nearest cities are well over 100 miles away (Roswell, NM and Midland, Lubbock and El Paso TX).

VIII. CONCLUSIONS

Massive salt deposits, such as the Salado Formation near Carlsbad, New Mexico, offers a ready solution to the disposal of nuclear waste from reprocessing spent fuel, a major impediment to solving our power generation and environmental needs in the next fifty years. This unit is already host to permanently disposed nuclear waste at the WIPP site. The extensive scientific investigations of this unit, a perfect safety record over the nine years of operation, and the recent disposal of higher-activity remote handled nuclear waste, demonstrate the capability of massive salt deposits, and of this type of operational environment, to handle nuclear waste of any type. Especially important is the removal of the need to vitrify higher-activity waste prior to disposal. Various salt and clay formations throughout the world can also serve as suitable nuclear waste repositories, having similar physical and isolation properties. From the standpoint of addressing operational and environmental risk, as well as public fear, any nuclear repository must have extensive monitoring of human health and the environmental, beginning from before operations, on the public, waste disposal workers, aerosols, water and soils.

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